3.0 THE WIND RESOURCE

3.1 Wind Data Collection and Analysis

In July 1994, the National Renewable Energy Laboratory (NREL) entered into a cooperative agreement with the Naval Facilities Engineering Service Center (NFESC) to collect one full year of high quality wind energy resource data at San Clemente Island (SCI) old Jacobs wind turbine facility, (Tower #6) at 18.3-m (60-ft) height. Three additional UNR-ROHN 43-m (140-ft) towers were installed by NREL crews at SCI sites Met2: 32° 59.236N by 118° 33.209W (at the present 450 kW wind turbine site), Met3: 32° 58.630N by 118° 33.977W (approximately 1 mile south of Met2), and Met4: 33° 01.248N by 118° 33.041W (Lemon Tank Reservoir). We examined the Met2 data in detail, and reviewed historical summary data to describe long-term wind characteristics.

The new data were collected through a full wind-energy meteorological sensor system including two anemometers, two wind vanes, a temperature probe, and a barometric pressure sensor. The anemometers were mounted 24.4-m (80-ft) and 42.7-m (140-ft) high at the new wind energy site on tower Met2.

Data collection began in August 1995, and continued through January 1999. All data was sampled at 1 Hz and then stored as 10-minute and 24-hour averages. The 10-minute average data was used for this report. Annual records of the 10-minute average wind speed, and the monthly records use daily averages. An annual record is derived for air density using

$$\rho = p / (R*T)$$

where ρ is density, p is pressure, T is temperature, and R = 0.286 kJ/(kg*K) for air. Then wind power density is derived using

$$P / A = 0.5 * \rho * V^3$$

where P is power, A is area, and V is wind speed. Using hourly average data, the diurnal wind speeds are created by computing an average for each hour of the day over all days in the period.

Wind direction data is difficult to present because the most common directions do not necessarily have the strongest winds. Therefore, this report includes three types of wind roses: percent time at each direction, average wind speed at each direction, and time-weighted average wind speed at each direction.

3.2 Historical Wind Data

This section begins with a review of 19 years of wind-speed data (1960-1978) at SCI station number 93117, compiled by Pacific Northwest Laboratories and archived by the National Climatic Data Center [2]. Historical annual average wind speeds follow in Figure 11.

The airfield began its operations in 1960 and the historical 19-year anemometer locations changed several times for this collection of historical wind data, and used different sensors, mountings, heights, exposures, and possibly drifting calibrations. Readings on the historical data were made 24 times a day after the first 3-years, which were read 5 to 11 times a day. The heights varied from 5.2 m to 7.9 m, so each year's data were adjusted to the wind turbine hub height [30.0 m (98.4 ft)] using the 1/7 power law. These low measurement heights are very susceptible to the effects of obstructions.

The average 19-year wind speed at SCI adjusted to the 30.0 m (98.4 ft) height is 4.0 m/s (7.8 knots) based on annual averages of hourly data, and the average of the annual standard deviations is 2.6 m/s (5.1 knots). The standard deviation of the annual averages is 0.7 m/s (1.3 knots), giving a variability of 0.7 / 4.0 = 0.175, or 17.5%. Although confidence in the average wind speed is low, this variability implies that the annual average wind speed will fall within +/- 53% (3 standard deviations) 99% of the time, assuming these values are normally distributed.

Some bias toward lower wind speed measurements is expected because of low heights, proximity to buildings and other obstructions, and possible binding (bearing or shaft roughness) of older anemometers. The airfield's altitude is 55.5 m (182ft). The ASR-8 Radar hill with an east-west ridge peaking at 160 m (524 ft) south of the airfield is approximately 2,300 m (7,500 ft) away. Although the ridge does not shadow the prevailing north to northwest winds, it can deflect them upward and cause lower measurements below. Winds from the northeast to southwest are sheltered. Because these factors are not tractable, no attempt is made to adjust the data to account for them. However, the averages found here are not used for the hybrid system modeling later in this report, but the interannual variability of 17.5% is used for the sensitivity analysis.

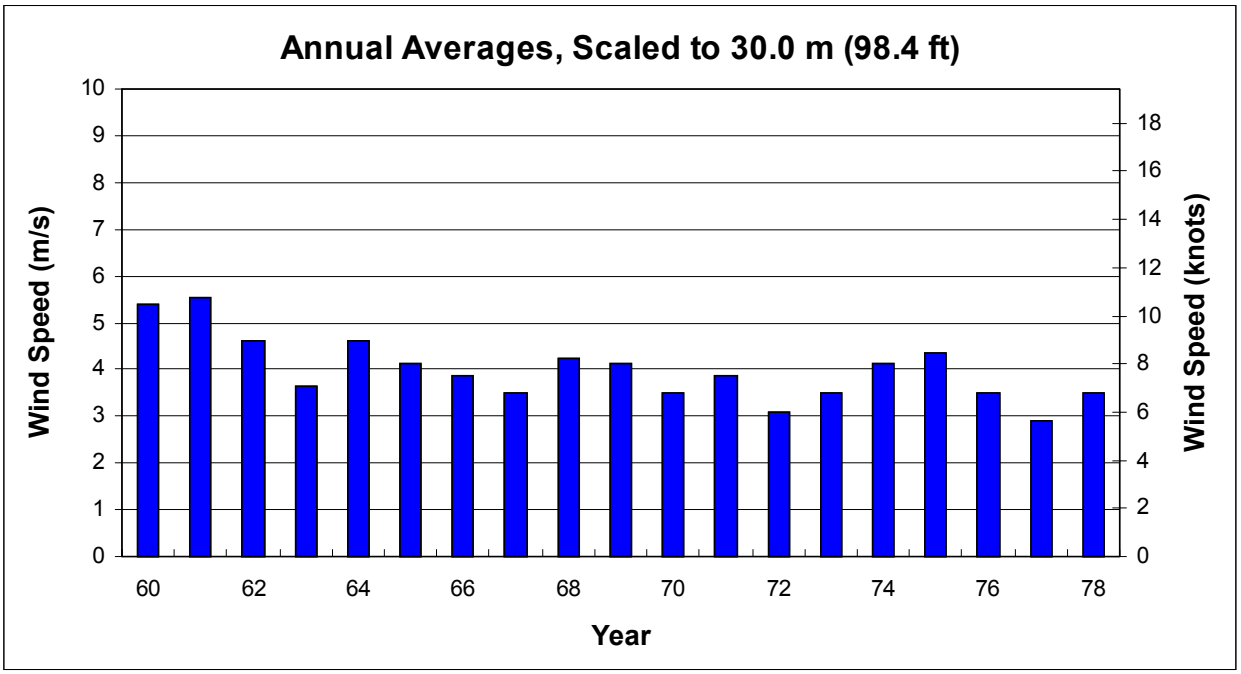

Figure 11: SCI Historical Wind Speeds

The following figures, 12 and 13, show some average diurnals from 1983-4 and 1984-5 collected at the old Jacobs site [3]. The data was collected with a MAXIM type 40 anemometer at 32 ft elevation and a Second Wind Datalogger Model A1-2002-4K. The average wind speed for both years at this site was 6.1 m/s (13.6 mph) at 9.8 m (32 ft) height, which would indicate a speed of 7.2 m/s (16.0 mph) at 30.5 m (100 ft) using the 1/7 power law.

	Wind Speed (mph) at												Avg	Diurnal
Year	0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200	WS	Swing
1983	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200	2400	(mph)	(mph)
Aug	11.6	11.5	10.5	9.4	8.9	10.0	13.5	18.0	19.8	19.6	17.6	13.4	13.7	10.9
Sep	11.5	10.6	10.3	9.1	9.8	11.1	13.6	16.5	18.3	17.9	15.5	12.3	13.0	9.2
Oct	11.9	9.8	9.8	9.5	8.3	8.1	10.0	12.9	15.1	14.5	14.3	12.4	11.4	7.0
Nov	13.6	12.9	12.5	12.0	11.6	12.9	13.4	15.1	16.4	16.1	15.6	15.1	13.9	4.8
Dec	13.5	13.8	12.9	10.6	10.8	12.1	14.4	14.6	13.9	14.3	13.4	12.9	13.1	4.0
1984														
Jan	10.5	10.8	10.3	9.7	8.5	9.5	9.8	11.9	15.1	15.9	15.1	12.1	11.6	7.4
Feb	14.6	13.4	11.6	11.6	11.8	13.0	13.8	15.6	17.6	18.1	16.9	15.5	14.5	6.5
Mar	13.3	12.1	9.8	9.5	11.1	12.3	14.4	17.0	20.4	20.6	18.9	15.9	14.6	11.1
Apr	17.4	14.9	13.6	13.0	13.9	16.8	20.5	24.1	24.4	22.8	20.8	18.9	18.4	11.4
May	12.3	11.5	10.5	9.1	10.3	11.4	14.0	17.8	18.4	19.2	16.8	14.8	13.8	10.1
Jun	11.1	9.4	8.9	8.5	8.6	9.9	11.9	15.9	19.0	18.6	17.0	13.5	12.7	10.5
Jul	13.9	12.5	12.4	10.9	9.9	11.4	17.4	20.8	19.0	17.6	17.8	16.8	15.0	10.9
Avg	13.1	12.0	11.1	10.3	10.4	11.7	13.9	16.6	18.0	17.8	16.6	14.6	13.8	7.6

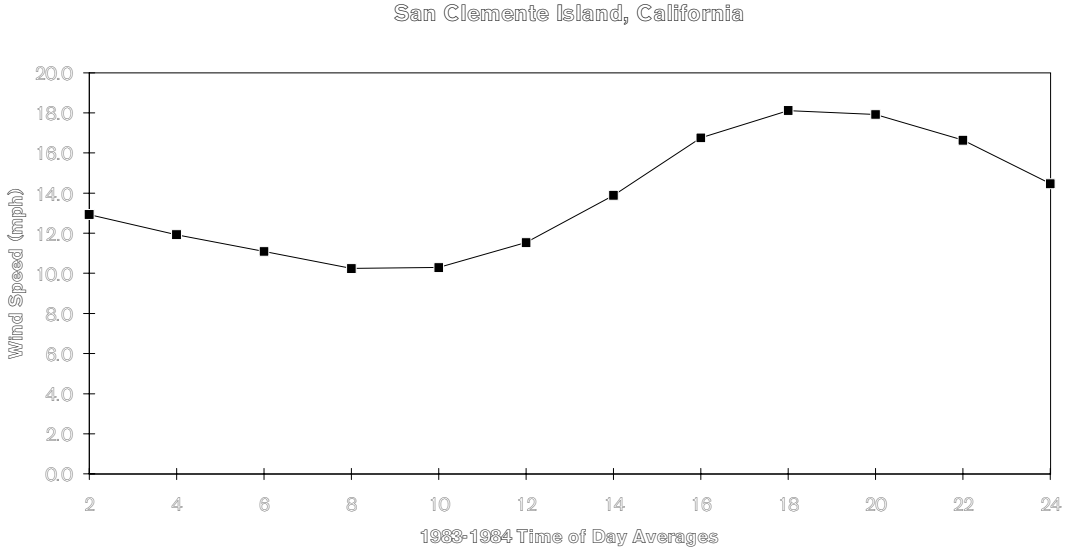

Figure 12: Annual Average Diurnal, Jacobs Site, 1983-4

Year	Wind Speed (mph) at 0000 1984	0200 0200	0400 0400	0600 0600	0800 0800	1000 1000	1200 1200	1400 1400	1600 1600	1800 1800	2000 2000	2200 2200	2400 2400	Avg WS (mph)	Diurnal Swing (mph)
Aug	11.4	10.5	9.6	8.6	8.2	10.0	13.2	17.2	19.0	18.2	15.9	12.9		12.9	10.8
Sep	12.5	12.2	11.4	11.2	11.2	11.9	14.4	17.1	18.5	18.4	17.5	15.6		14.3	7.3
Oct	12.8	12.5	11.4	11.2	12.2	13.8	14.5	17.1	19.4	18.9	15.5	12.6		14.3	8.2
Nov	12.1	12.2	11.5	11.2	11.2	12.2	13.8	14.2	14.9	13.6	13.1	13.1		12.8	3.7
Dec	10.8	9.9	10.5	10.9	10.8	11.2	10.8	11.1	13.1	13.1	12.6	11.2		11.3	3.2
1985															
Feb	10.5	10.1	10.1	9.6	9.9	10.8	11.5	13.1	13.0	12.9	12.2	11.9		11.3	3.5
Mar	14.4	13.8	12.9	12.4	12.9	14.2	16.8	18.5	19.6	18.6	16.6	15.1		15.5	7.2
Apr	13.6	11.4	11.1	10.5	10.8	12.4	16.0	17.9	19.4	18.2	15.9	14.2		14.3	8.9
May	12.4	11.8	10.5	9.6	10.8	10.8	13.6	18.4	20.2	18.9	16.2	14.2		14.0	10.6
Jun	10.2	9.6	8.9	8.8	9.0	9.8	12.5	14.4	16.9	17.0	13.5	11.1		11.8	8.2
Jul	13.1	11.6	10.2	10.1	10.1	11.5	14.5	18.1	20.8	21.9	18.4	15.5		14.7	11.8
Avg.	12.2	11.4	10.7	10.4	10.6	11.7	13.8	16.1	17.7	17.2	15.2	13.4		13.4	7.3

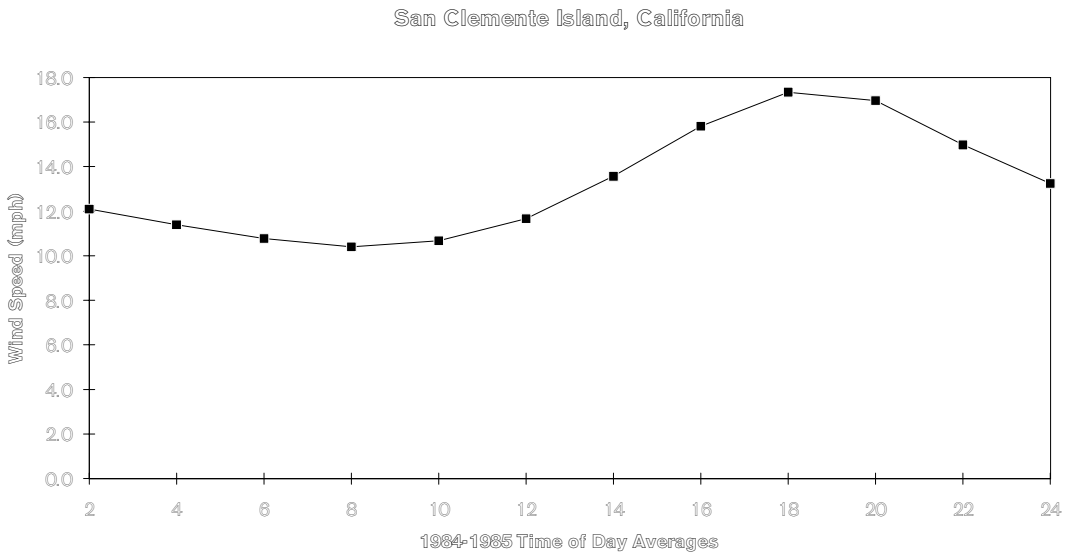

Figure 13: Annual Average Diurnal, Jacobs Site, 1984-5

3.3 Current Wind Data

Data were collected between August 1995 and January 1999 at the 43.6-m (140-ft) meteorological tower number 2 at the designated SCI Wind Turbine Site. The wind speed data was collected at 43.6-m (140-ft) height and temperature and pressure at 3-m (10-ft).

The data collection rate was about 75%, with several gaps spread throughout the data sets. This low collection rate is attributed to a lack of available staff for checking, downloading data, and maintaining the site data acquisition systems. In addition, the data shows error rates of 5 to 10%. Because no year has a full data set, a composite 10-minute data set was created to use for generating a wind speed histogram, annual diurnal, wind rose, and hourly data for hybrid system modeling. Using 1998 as the baseline data set, both missing data and bad data segments were filled in with good data segments from the other years as itemized in Table 3.

Table 3: Source Years for Composite Wind Data Set

Julian Day	Source Year
1-31	1999
32-36	1996
37-238	1998
239-273	1995
274-284	1998
285-287	1995
288-365	1998

Statistical analysis of the last 3-years of daily meteorological data yielded the results shown in Table 4, and a full wind speed distribution is presented in Figure 14. Subsequent hybrid system modeling used the composite data set adjusted to wind turbine hub height. The 10-minute data set was not used here because of the amount of manual processing required to remove bad data segments. However, the 10-minute data would indicate somewhat higher standard deviations of 3.3 m/s and lower minima of 0.0 m/s (both affected by bad data), with maxima reaching 25.9 m/s.

Table 4: Summary of Current SCI Meteorological Data

Channel	Units	Average	Standard Deviation	Minimum	Maximum
Wind Speed, 1996	m/s	6.1	2.7	1.8	16.9
Wind Speed, 1997	m/s	5.5	2.6	1.4	18.0
Wind Speed, 1998	m/s	6.6	2.7	2.3	17.0
Wind Speed, composite	m/s	6.4	2.7	2.3	17.0
Wind Speed, composite	knots	12.4	5.2	4.5	33.0
Ambient Temp, 1998	°C	14.4	2.5	8.2	22.8
Ambient Pressure, 1998	mbar	990	3.3	981	1002
Air Density, 1998	kg/m^3	1.20	0.01	1.17	1.24
Power Density, 1998	W/m^2	267	400	7.6	2990

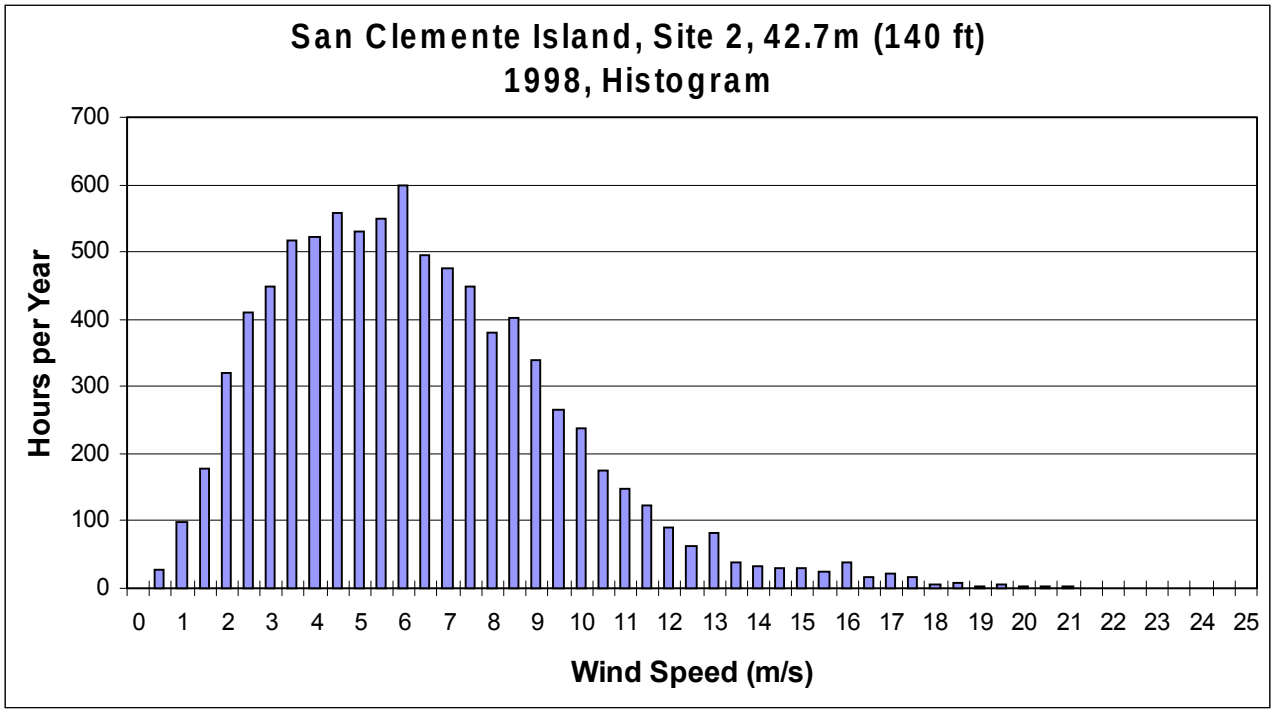

Figure 14: SCI Wind Speed Frequency Distribution

Annual records using monthly averages have been plotted for wind speed, ambient temperature, ambient pressure, air density, and power density. The source data were derived from NREL testing on SCI at 42.7-m (140-ft) on tower Met2 for the August 1995 through January 1999 period. Missing and bad data segments were removed from the daily and monthly-averaged data for these records. Wind-speed records for 1995 through 1999 appear in Figures 15-19, and records for other meteorological parameters in 1998 are shown in Figures 20-23.

Wind speeds are fairly consistent at this site; no months stand out as significantly higher or lower between the 3-years examined. The wind speed range generally falls between 5 and 8 m/s. Temperature and pressure cycle gently with more warmth and lower pressure in the summer, causing slightly lower summer densities. Power density looks like an exaggeration of wind speed, as expected from its cubic relationship.

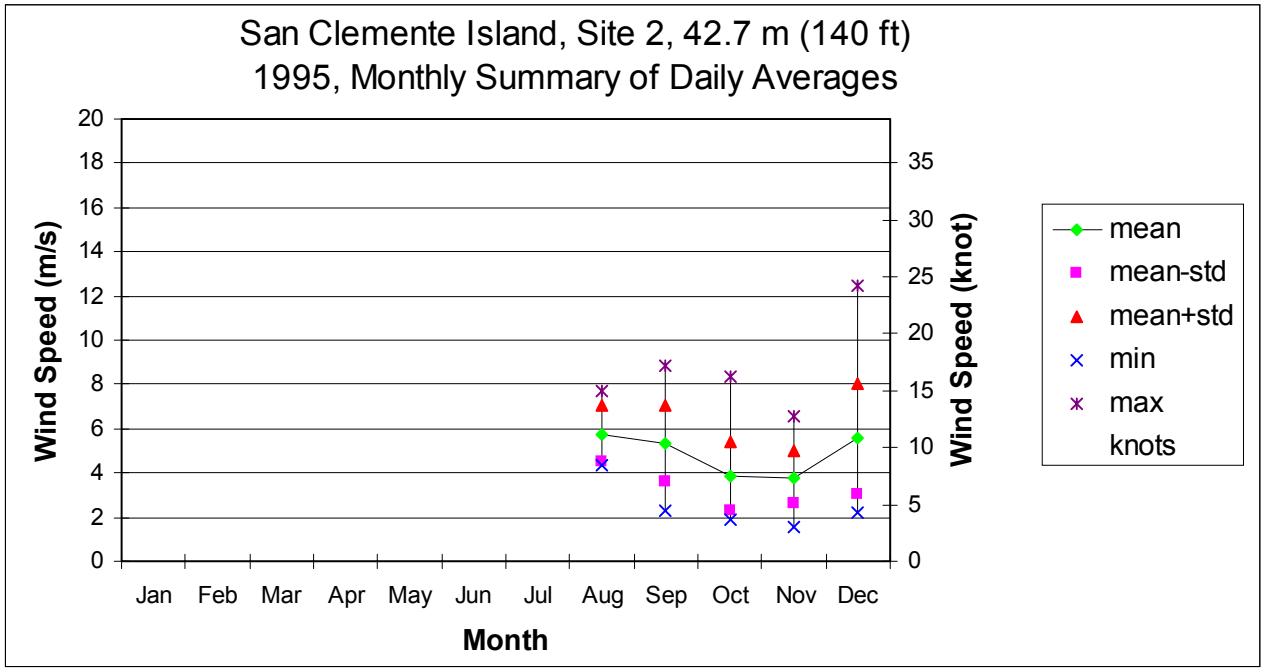

Figure 15: SCI Monthly Averaged Wind Speed, 1995

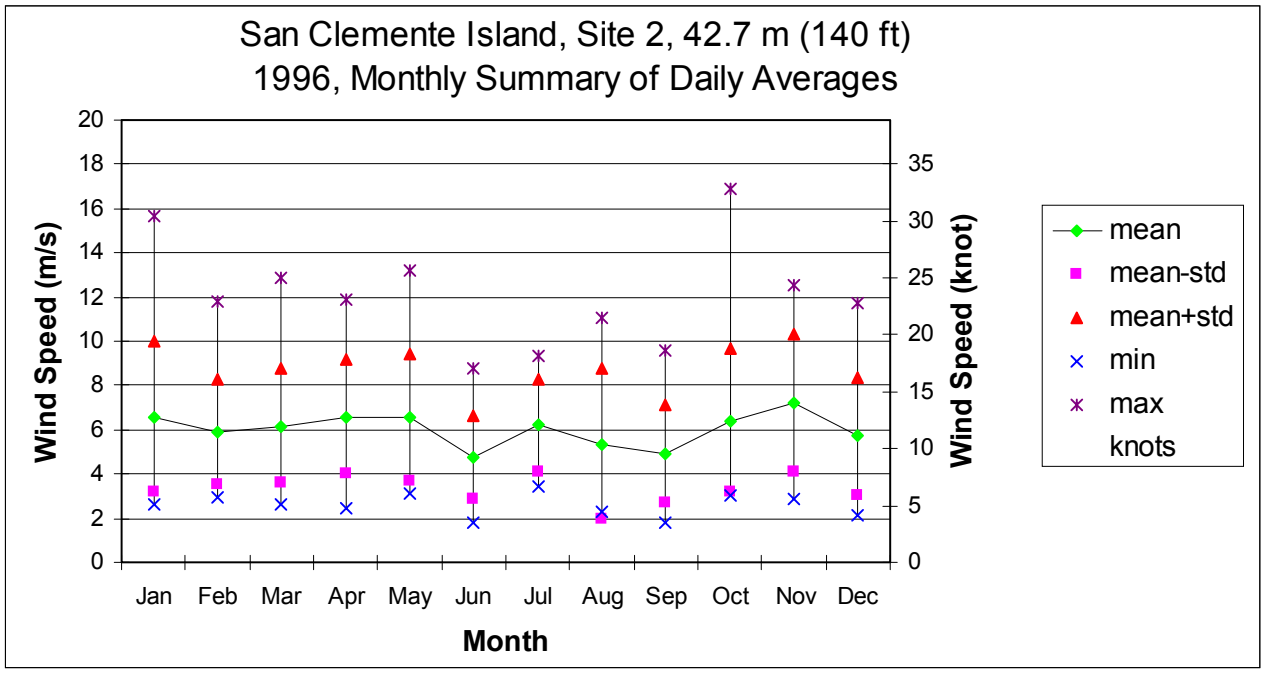

Figure 16: SCI Monthly Averaged Wind Speed, 1996

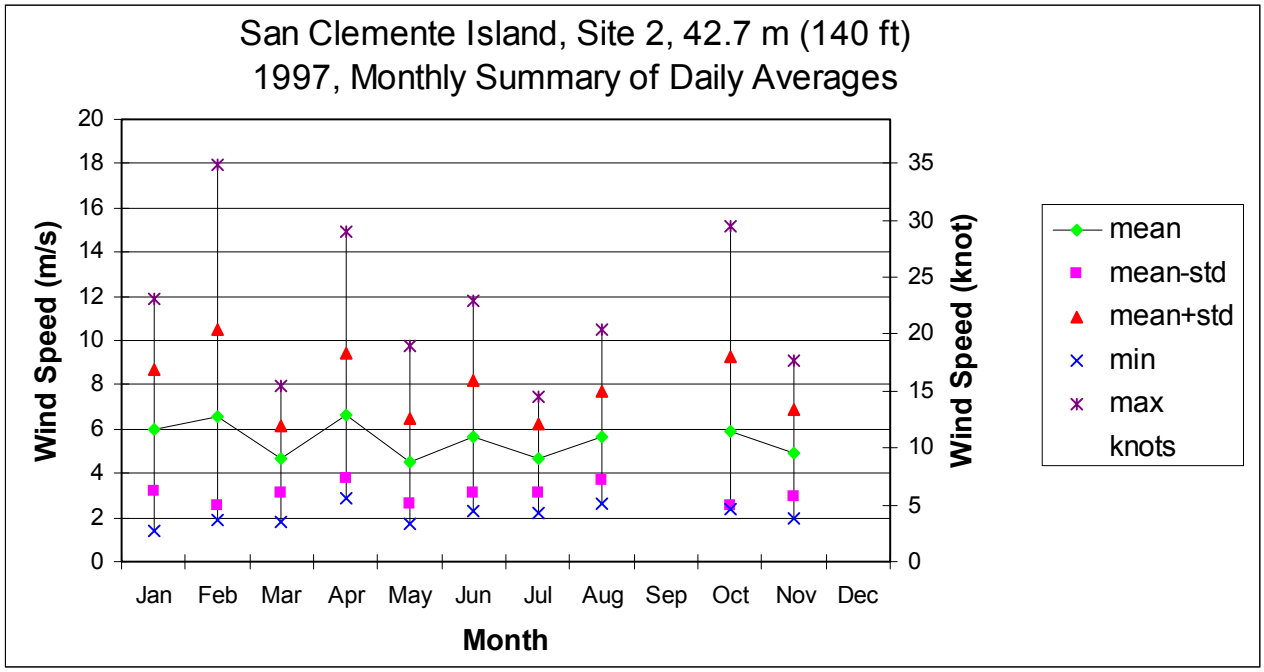

Figure 17: SCI Monthly Averaged Wind Speed, 1997

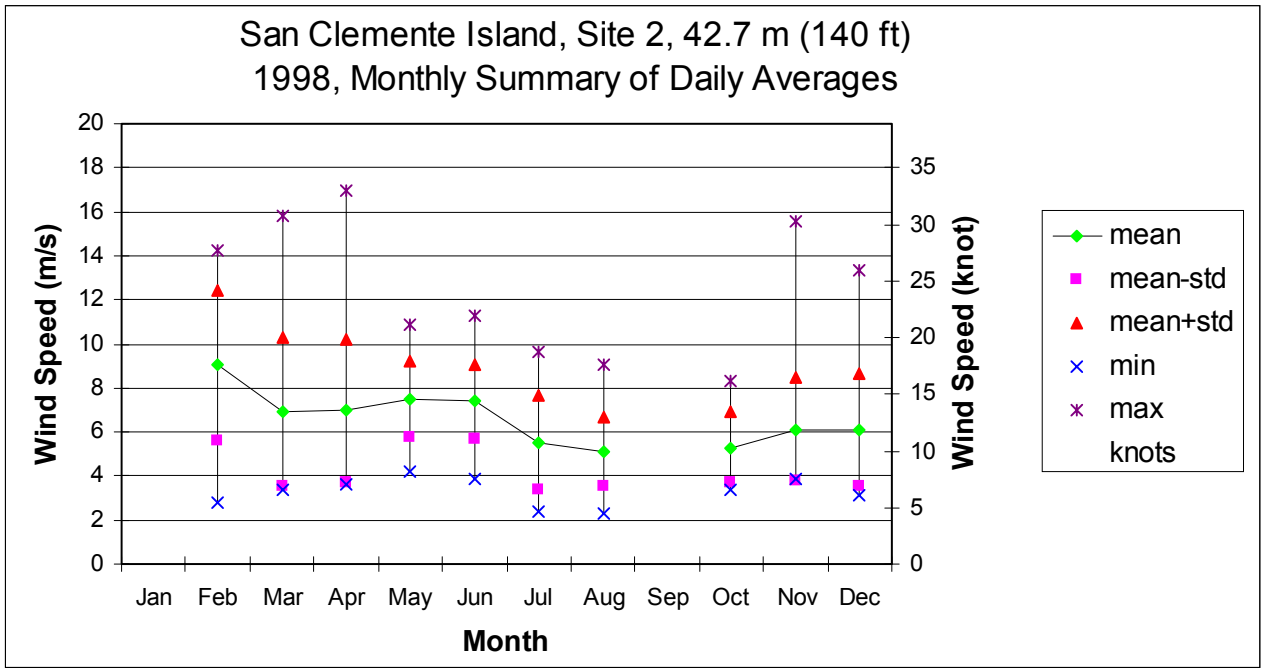

Figure 18: SCI Monthly Averaged Wind Speed, 1998

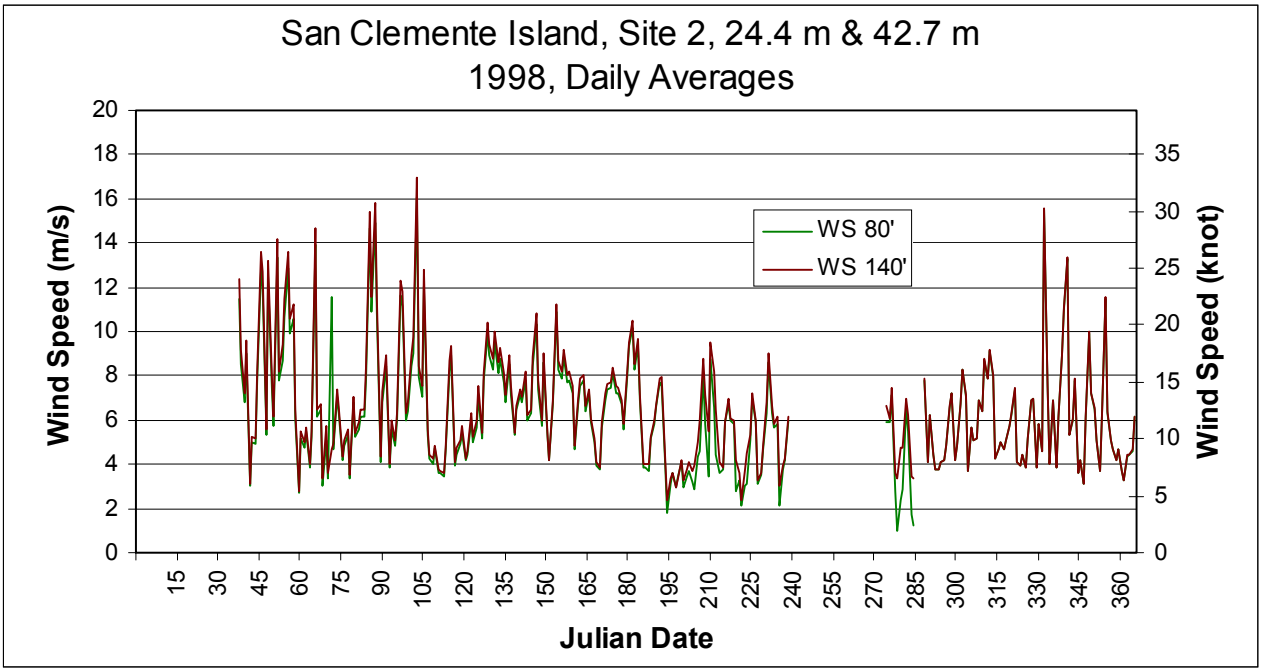

Figure 19: SCI Daily Averaged Wind Speed, 1998

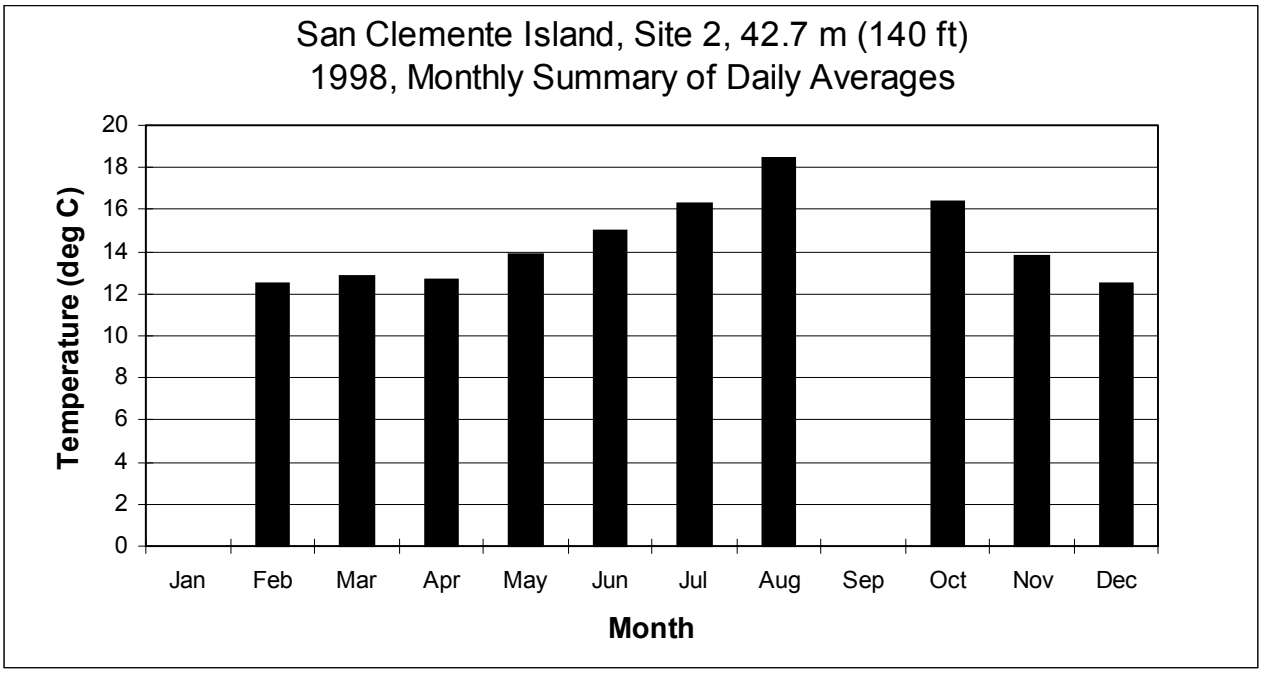

Figure 20: SCI Monthly Averaged Temperature, 1998

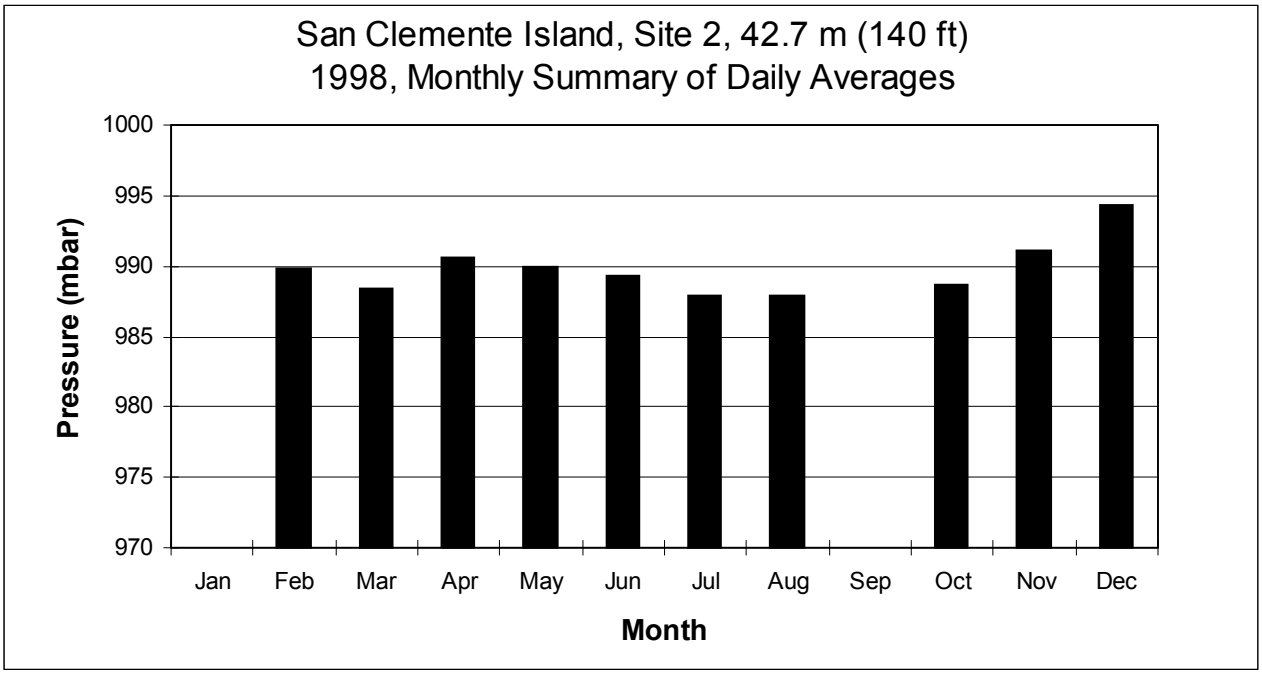

Figure 21: SCI Monthly Averaged Pressure, 1998

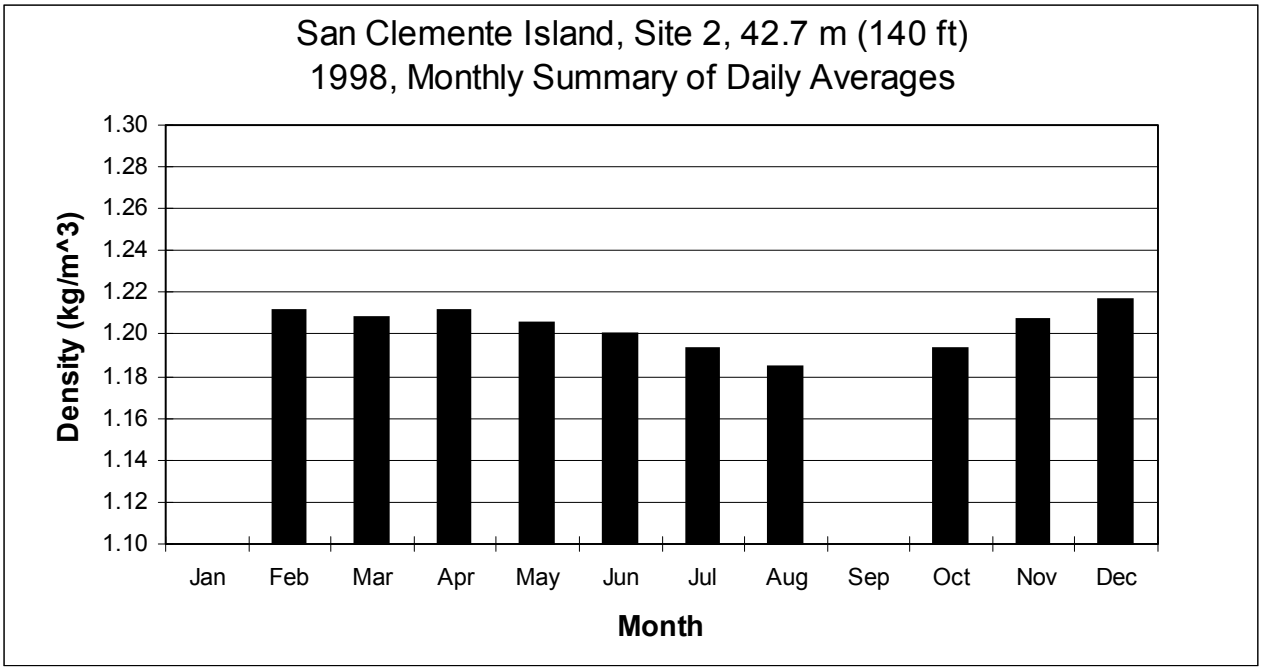

Figure 22: SCI Monthly Averaged Density, 1998

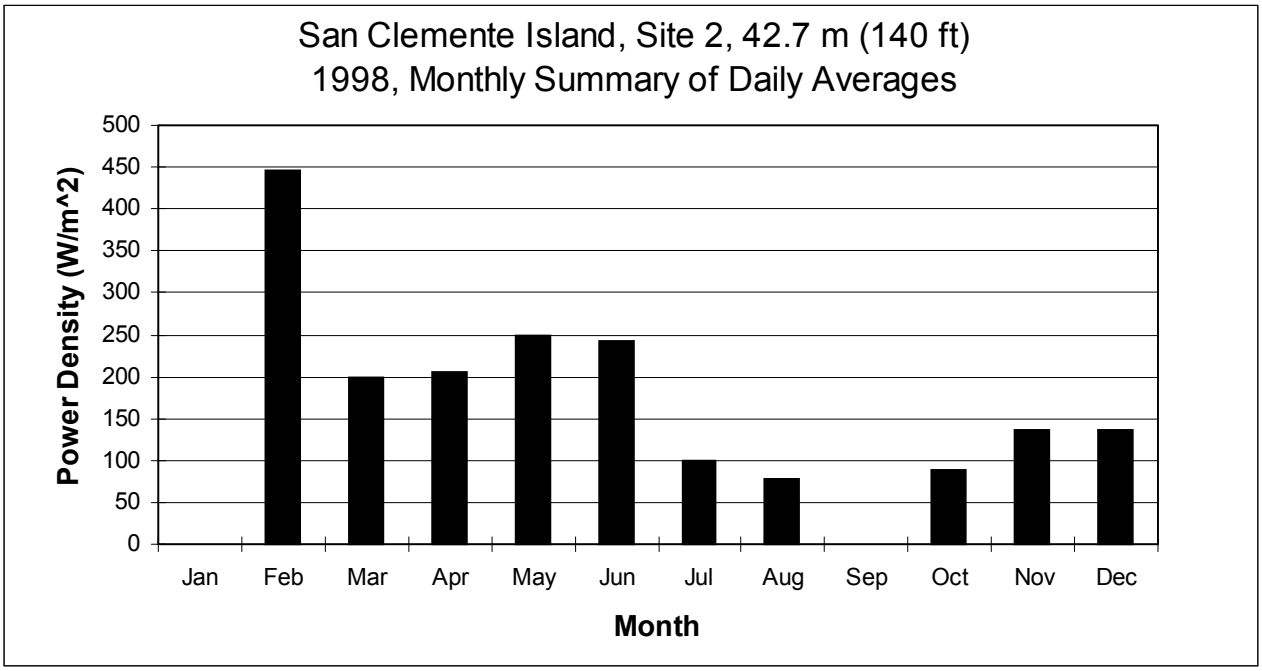

Figure 23: SCI Monthly Averaged Wind Power Density, 1998

The annual average diurnal given in Figure 24 shows a stable pattern, with wind speeds falling between 5 and 7.5 m/s. They are slightly lower through night and morning, and slightly higher through the afternoon and evening. The diurnal is derived from the 1-year composite hourly data set described earlier. Each hour is averaged through the whole year; any specific day could be quite different. For reference, the column labeled "0000" refers to the first hour of the day: 0000 to 0100.

The wind roses shown in Figures 25-29 also use the composite hourly data set. They indicate prevailing winds from the west and west by northwest, with somewhat stronger average wind speeds in these directions as well as in the northwest, southwest, and south.

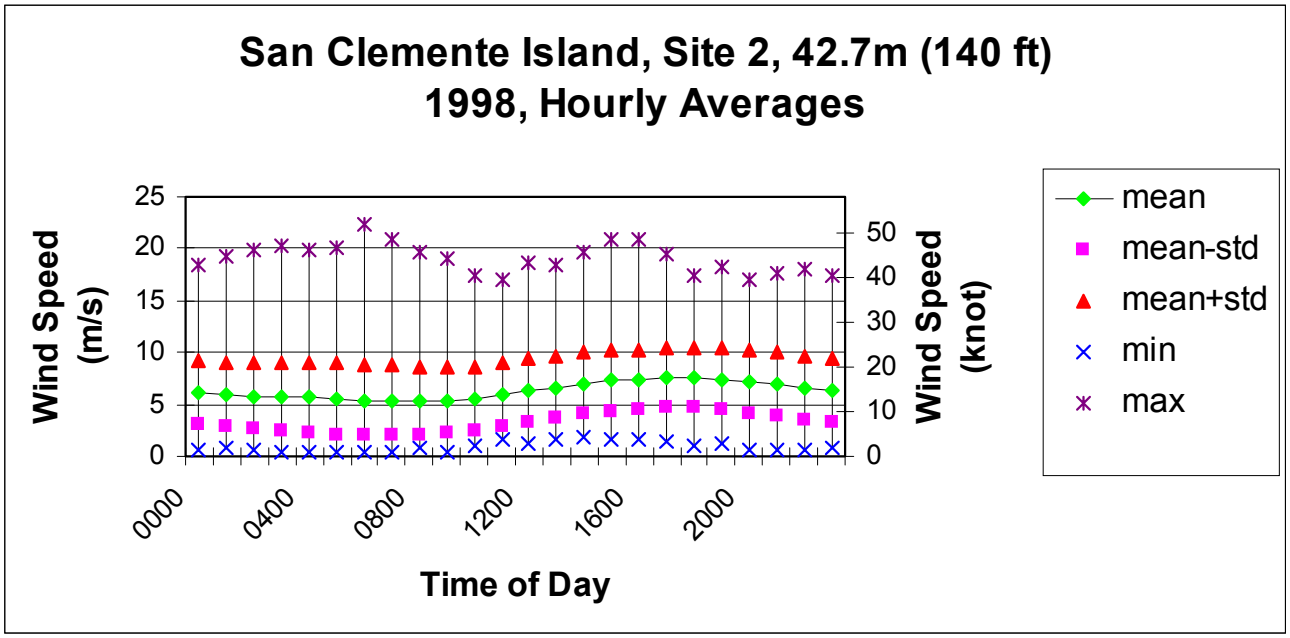

Figure 24: SCI Annual Average Diurnal Wind Speed

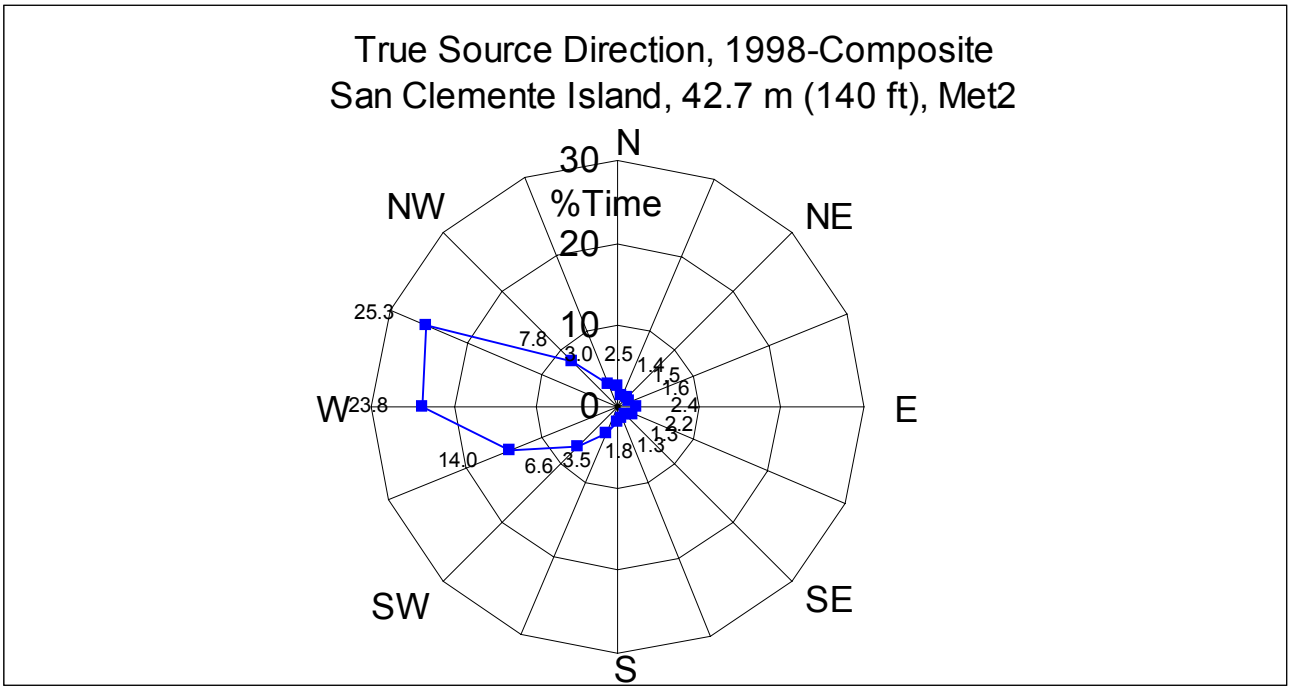

Figure 25: SCI Wind Rose: Percent Time

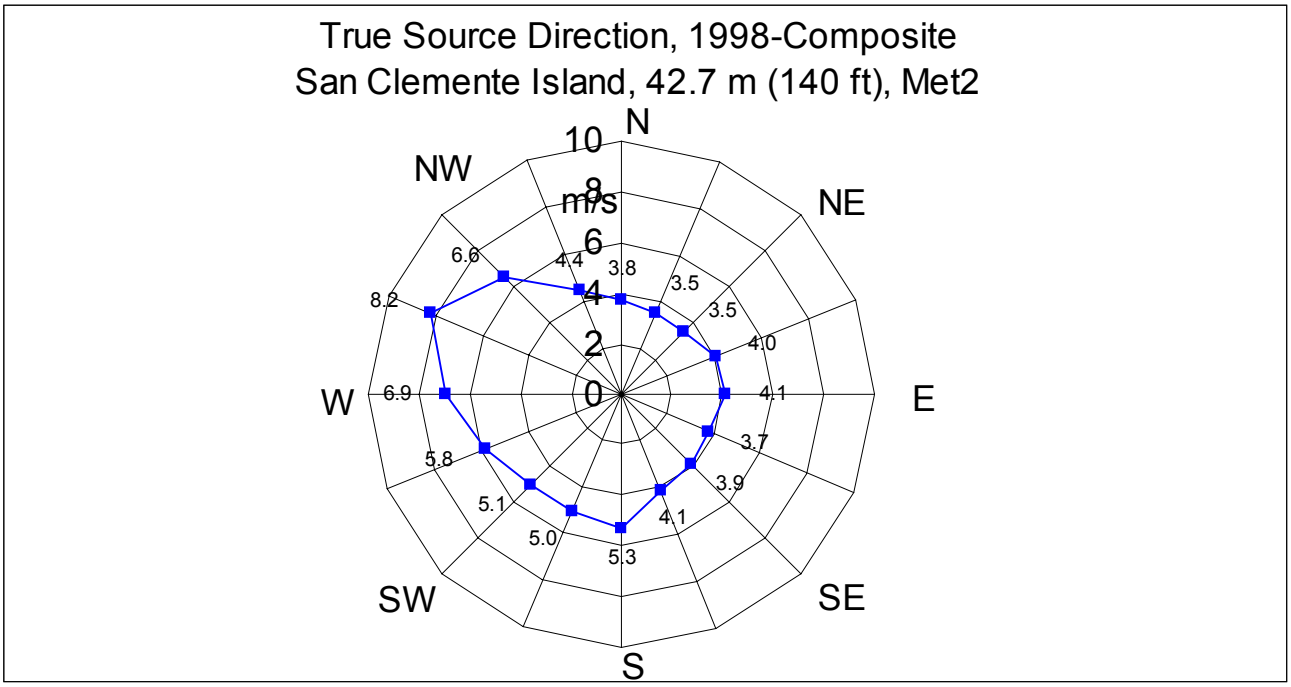

Figure 26: SCI Wind Rose: Average Wind Speed (m/s)

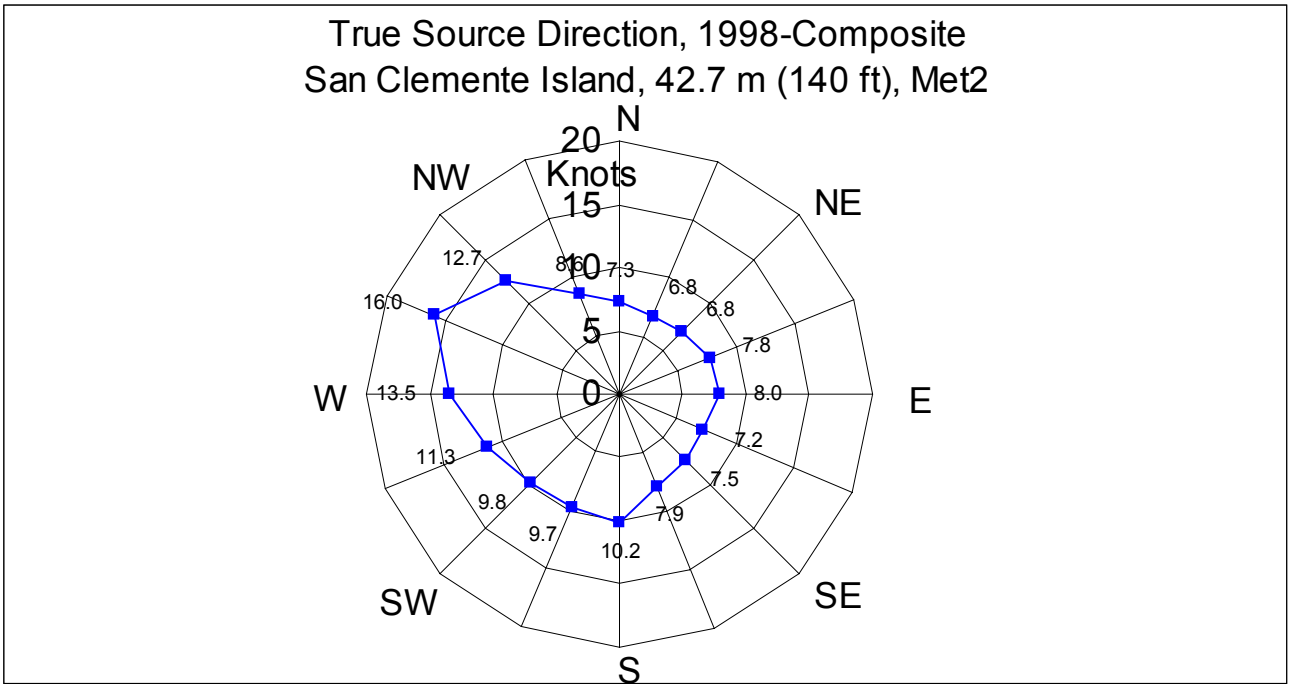

Figure 27: SCI Wind Rose: Average Wind Speed (knots)

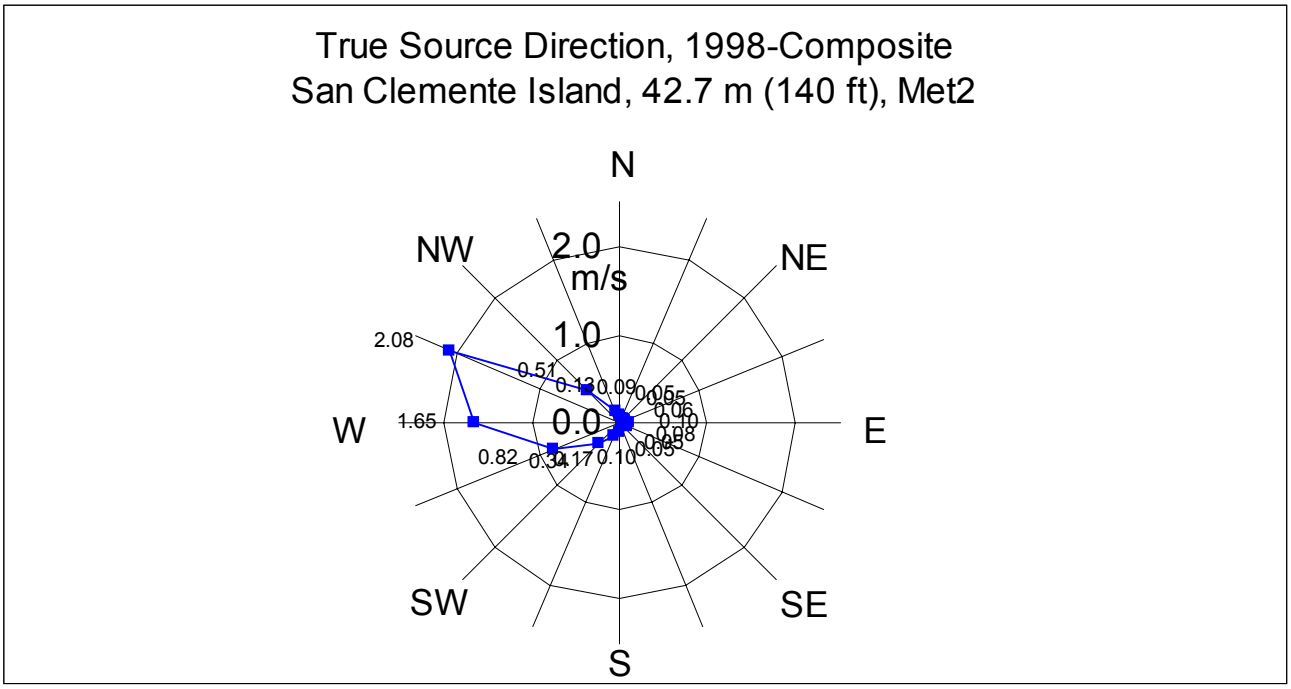

Figure 28: SCI Wind Rose: Time Weighted Average Wind Speed (m/s)

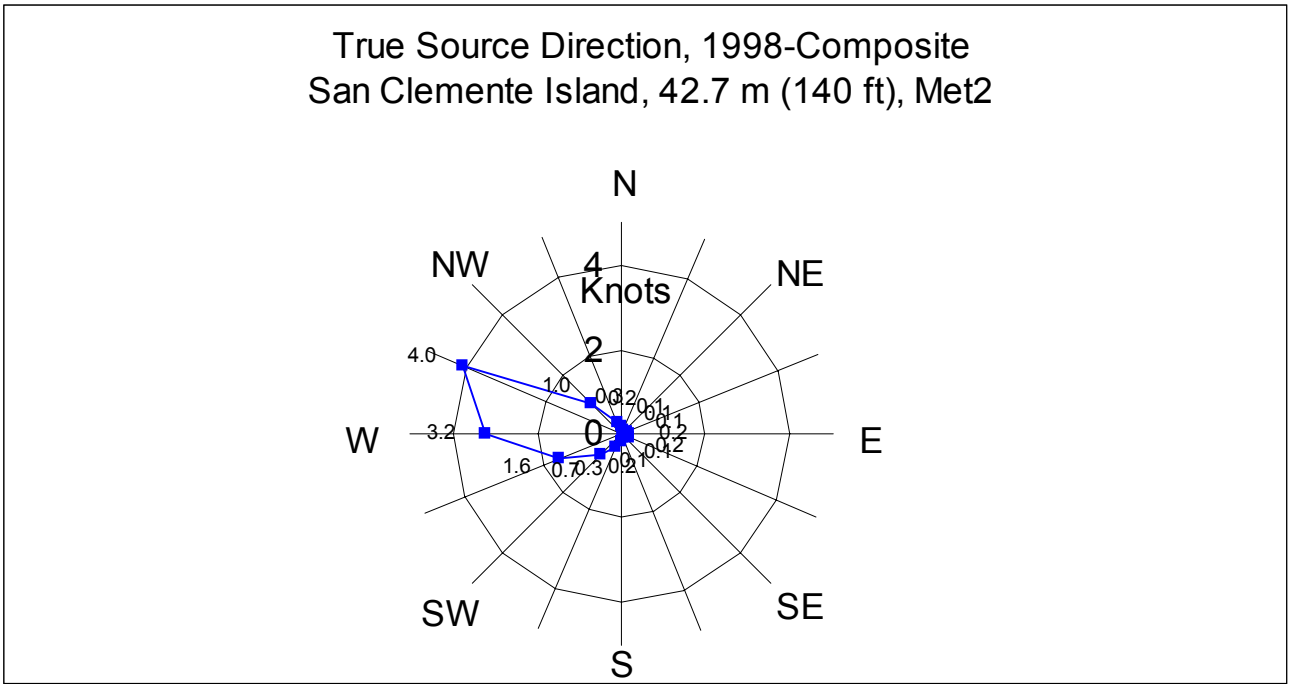

Figure 29: SCI Wind Rose: Time Weighted Average Wind Speed (knots)